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THE DETECTION OF THE COAL ROOF INTERFACE

BY USE OF HIGH PRESSURE WATER

Final Report

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ABSTRACT

The need for automatic positioning of the ranging drums of the longwall shearer devices increasingly being used in the United States increases as the speed of the machine increases and as the seams being mined grows less.

A device is herein described whereby water jets can be used to detect the interface between coal and the overlying roof rock. Once this identification is made this distance can be measured using instruments such as the autofocus systems recently developed in the photographic industry.

Experiments have been carried out to show that the device can discriminate between coal and rock at coal thicknesses up to 8 inches. An autofocus system has been examined which indicates that accuracies of better than 0.1 inches can be achieved.

Recommendations for further investigation are made.

CHAPTER ONE

INTRODUCTION TO THE PROBLEM

Introduction

There has been, within the past few years, a growing trend within the United States toward the adoption of longwall mining as a means of extracting coal underground. In this method of mining a machine, typically either a shearer or a plough, is translated along a coal face, typically of the order of 200 yards long, removing as it passes a strip of coal and loading it onto a sub-adjacent conveyor. The speed of the machine and its cutting ability are controlled generally by two operatives who travel along the face with the machine. In the case of a shearer, however, the ability of the operator to identify the exact location of the cutting drums of the machine as it is advancing is not always adequate. In consequence, the machine may cut either into the roof or the floor of the coal seam, creating, in turn, excessive wear on the cutter picks and slowing the machine advance, concurrently more dirt is produced by the machine, lowering saleable productivity and requiring a more expensive cleaning of the coal. These factors combine to give high losses in productivity directly attributable to the inadequate steering of the machine. It would therefore be of potential economic benefit, since the operator of the unit cannot be placed in closer proximity to the cutting head, if an automatic device were developed to sense and control the exact position of the cutting drums.

The operation of large size shearers, particularly in the thicker seams which are now being mined by longwall means, in the United States, has also meant that larger roof supports are required. In such instances, situations can occur where the bearing strength of either the

immediately overlying roof or the underlying floor is inadequate to support the thrust likely to be brought upon it by the roof supports as they move forward to hold open the cavity generated by the mining machine. In such circumstances (Ref. 1) it is not uncommon for coal to be left as a support layer, either immediately below the horizon the machine has worked, or immediately above it. Typically, in such circumstances, thicknesses of coal of the order of 6 inches may be left. Leaving this coal brings an added complication to the task of steering the machine, since the emplacement of the cutting drums within the coal seams horizon means that there is no readily identifiable line to which the operator can direct the cutting heads. This exacerbates the problems of steerage and makes it difficult to maintain the exact thickness of coal required by the ground support. Under these circumstances a further advantage to the automatic location of the machine relative to an interface between the coal and shale can be seen.

The problem of interface detection is, however, not consistent in the floor and the roof locations. While it is possible in either instance to require that a layer of coal be left between the operating horizon and the underlying rock, nevertheless, where coal is left in the roof this coal will form part of a major support to the overlying roof layers, and if weakened may fall out, due to the forces of gravity. Congruously, the coal left underlying the horizon, while not subjected to as great an extent to the gravitational effect, and the complicating effects of the ground arch support, will, rather, be subjected to the passage of the machine, and may become submerged or become buried under the water spray and dust generated by the machine passage. It must, therefore, be considered as a separate case.

Current Practice

The major method of detecting the interface between the coal and the surrounding rock at the present time has been through the use of the nucleonic sensor (Ref. 2). This sensor generally (Ref. 3) consists of a radioactive source, typically generating gamma rays which penetrate into the coal and overlying rock and are back scattered as they pass. The degree of backscatting can be monitored by an adjacent detector and calibrated to the thickness of the coal layer. The two elements, source and detector, are combined in a single sensor unit between 3 and 4 ft long. This method was first successfully used on a longwall face in 1969 and showed sufficient benefit that, by 1975, twelve units had been installed underground (Ref. 2) with some 30 additional units planned.

There are, however, certain problems with the use of such a system and while the installations have shown the considerable advantages in terms of cleaner product, faster and therefore more productive shearer operation, better roof control, such that, for example, the first unit could have been said to pay for itself in seven weeks (Ref. 3), nevertheless, the system to date has several critical problems (Ref. 3, 4) suggesting that further improvements can be made.

The problems in the operation of the sensor include the requirement that it maintain positive contact with the solid coal, that it be periodically recalibrated to cope with the variation in coal: rock properties, that it has an accuracy of $\pm$ 1 in.; that because of its size and location, it makes bi-directional cutting impractical; that it requires high quality and stringent maintenance; that the range of the unit is limited to less than 10 in.; that it is sensitive to changes in the relative density of the rock and coal and to the variations of dirt and dirt bands in the overlying coal; the unit also can only work, at present, in

thicker seams; the coal sensor output is taken over 10 sec and therefore takes an average over perhaps 1 yard of roof; the sensor does not measure a point value, but, rather, is influenced by the area of coal over the source and detector.

For these reasons alternate strategies are being investigated under funding, through the National Aeronautics and Space Administration, and from the Department of Energy. Of these alternate possibilities, the possible applications of high pressure water jets are the subject of this report.

Water Jet Potential

There has been a large and growing interest in the use of high pressure water jets as a means of cutting coal over the last decade. Recently, a major hydraulic mine in the west of Canada has been able to produce coal at production rates of up to 3,500 tons per shift from a single unit, indicating a high potential productivity where hydraulic mining is used. The parameters of such operations, however, require that relatively high volumes of water, greater than 200 gallons per minute, are required at low pressure, and that the coal is indiscriminately removed. What is required in order to achieve the objectives outlined in this program is a water jet system which is capable of cutting through perhaps six inches of coal and discriminating between this coal and the underlying rock.

Experiments carried out at the University of Missouri-Rolla have shown that water jets are extremely localized in their cutting ability upon a rock target. For example, in the cutting of sandstone, water jets of the diameter of approximately .040 inches are capable of cutting to a depth of 2 inches in the sandstone in paths that run parallel to

one another, but less than 0.1 inches apart (Fig. 1). Conversely, when two adjacent water jets cut through coal, as during the development of the longwall water jet mining machine, it was found at an included angle of up to 20 degrees, that the jets will cut out to a distance of perhaps 27 inches from the nozzle, while removing all the intervening coal between the two jet systems (Fig. 2). This cutting ability of the water jets is related to the structural parameters of the coal.

Coal is unique among rock structures in that not only is the coal laminated horizontally by bedding planes, but it is also delineated vertically by cleavage planes and cleat lines across which coal has essentially no strength in tension. Thus, where the water jet impacts upon such a plane, the water is able to infuse along the plane which, becoming pressurized, is weakened and coal can be easily moved to the free side of such a plane.

A discriminatory parameter between rock and coal can therefore be identified. In rock, water jets are confined in cutting action to areas almost directly underneath the cutting jet, whereas in coal, it is possible for the water jet to remove material to some distance laterally away from the jet axis and cutting plane of the impacting water jet.

Two different approaches were initially considered as being means by which this discriminatory effect could be utilized in establishing the boundary between coal and surrounding rock materials. One of these was the use of a rotating water jet to drill, on an eccentric axis, a hole into the roof of the coal seam. This hole would, thus, be drilled using the water jet to cut only along the periphery of the cylinder established, but as the jet cut upward, all the coal within the periphery would be removed, however, once the water jet cut into the overlying rock, only a slot would be established leaving the central core of the

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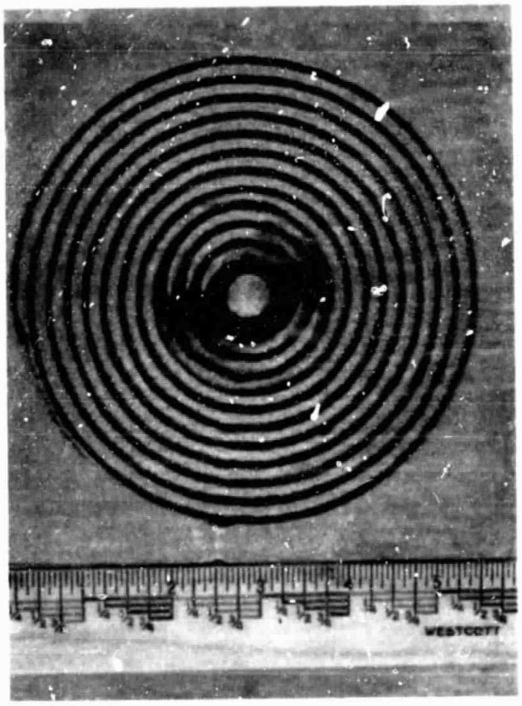

Fig. 1. Circular cuts in Berea sandstone showing that ribs less than 0.1 inch wide are not removed.

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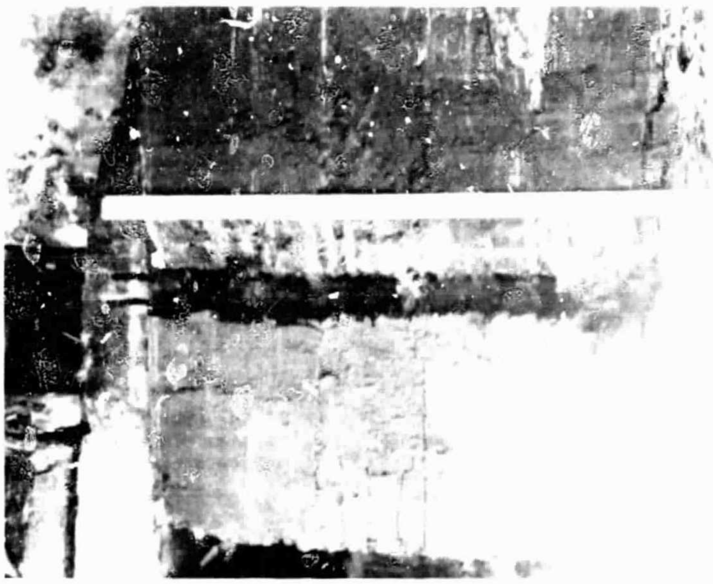

Fig. 2. Two adjacent cuts in coal 2 inches apart, showing the removal of intervening material.

rock intact. A means of measuring the depth of this hole could then be established, and this would identify the distance through the coal to the overlying rock interface.

This approach cannot be considered in the case of the layer of coal between the machine and the underlying rock in the floor because gravity will not act to remove the central core of the coal. Concurrently, such a hole, if created, will rapidly fill with water and other debris and the jet will not be able to keep this clean until the measuring instrument is inserted. For this reason it is conceived that an oscillating water jet arm, cutting down to the rock interface could be utilized in this location. The oscillation of the arm can be controlled, and since the water jet will cut a wide path in the coal, while only notching the underlying rock without removing the rib between two adjacent jets, then it will be possible to monitor the location of the interface. The oscillating jets will continue to keep the slot clean long enough for the interface to be addressed, since the slot will continue to be cut along with the machine advance. This approach would not be feasible in the location at the top of the seam, since were such a method to be tried then the coal support beam would be severely weakened by the water jet action with unfortunate consequences to the stability of the roof during subsequent mining.

An evaluation of both these approaches led to the conclusion that it would not be possible, within the confines of the existing contract, to fully develop and evaluate them both. Accordingly, it was determined that since the overlying coal layer problem was perhaps the more technically difficult, while concurrently demonstrating the concept which holds equally for both systems, that this would be undertaken.

Several advantages can be foreseen for this system, no positive

contact with the roof is required; no calibration will be required; depending on the final sensitivity of the measuring system potential accuracies up to 1/100ths of an inch are possible; the system can be mounted in a small space to allow bi-directional shearing, the system can be made sufficiently simple and compact as to require infrequent maintenance by regular face operatives; the range is limited to 6 ft, at present, the system is relatively insensitive to changes in rock and coal properties or the presence of thin dirt layers in the coal; the unit can be used in any seams a shearer can be used; the reading is taken in less than 2 seconds; once the unit has passed, a skeptical face worker can visually verify the accuracy of the unit, and also observe the overlying strata.

Experiments to verify the viability of the concept were set up at the Rock Mechanics and Explosives Research Center of the University of Missouri-Rolla. The purpose was to evaluate the parameters that would be required for a water jet system to cut through a layer to an overlying rock seam in such a manner as to discriminate between the coal being cut through and such rock. Concurrently, the program would be restricted to looking at a maximum coal thickness of 8 inches and it was agreed that an accuracy of .5 inches in such an indentification would be satisfactory. Concurrently, a secondary program would look at the potential methods which could be used to establish the depth of the hole created in the coal by the water jets and thus identify the location of such an interface for the mining machine to follow.

CHAPTER TWO

WATER JET CUTTING OF COAL AND ROCK

Introduction

In evaluating the practical parameters of the system to be developed, it was concluded that the present state of the art in high pressure water jet systems and the couplings and fittings therefore would preclude use of any water jet pressures much in excess of 15,000 psi. This pressure level is currently in common usage for the high pressure cleaning of industrial chemical plants, in the North Sea for the cleaning of oil rigs, and is finding application in the water jet cutting of materials (Ref. 5). Concurrently high pressure rotary couplings have been tested and performed satisfactorily at this pressure and are included in commercially available water jet cleaning systems (Ref. 6, 7). The equipment was also limited in size to that which would be generated by a 75 hp pump currently available at the University. It was considered that any system which would require a higher horsepower than this would be using more horsepower to detect the interface than would be used for mining the coal, and this would be, at best, an unproductive exercise. The experimentation was therefore confined within these parameters.

Equipment

High pressure water, mixed with a small amount of soluble oil for pump lubrication, was provided from a Kobe Size 3* triplex pump mounted in the Jet Cutting Facility of the Rock Mechanics & Explosives Research Center. The fluid was transmitted, through a 0.5 inch internal diameter

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high pressure hose to a manifold, constructed at the University. This manifold, of 6 litre capacity, was designed to remove the pulsations from the fluid flow and also served as a point where the pressure could be monitored. A conventional bourdon tube pressure gage was installed in the manifold for this purpose. A high pressure (30,000 psi burst pressure) hose was then used to carry the fluid to the test stand.

The test stand comprised a table, upon which samples could be placed, and, mounted underneath, a rotary drilling system (Fig. 3). The table was constructed with a shutter mechanism mounted under a central orifice on the support platform. The shutter was operated manually and was used to control the duration of the jet action on the target sample.

The rotary drilling system comprised a Harwood swivel coupling, supplied with fluid by the flexible hose, and from which a length of high pressure tubing was directed vertically to the cutting nozzle. This tubing, 1/4"I.D., 9/16"O.D., was bent so that, as it rotated, the ensuing jet would describe a cylinder. Three separate tubing sections were prepared so that this degree of eccentricity could be changed from 1/2" to 3/4" to 1" eccentricity. Rotation of the pipe was achieved through a sprocket and chain drive from a Char Lynn hydraulic motor to a sprocket attached to the high pressure tubing. The flow of oil to the hydraulic motor was infinitely variable within a fixed range so that the speed of rotation could be adjusted to up to 1,000 rpm.

Four nozzles were used in the test program, of exit diameters respectively 0.02, 0.03, 0.04, and 0.064 inches. The nozzles conformed to Leach and Walker geometry (Ref. 8) and were constructed from mandrils upon which nickel was electroformed, in order to attain the correct surface finish. The nozzles were attached to the end of the tubing

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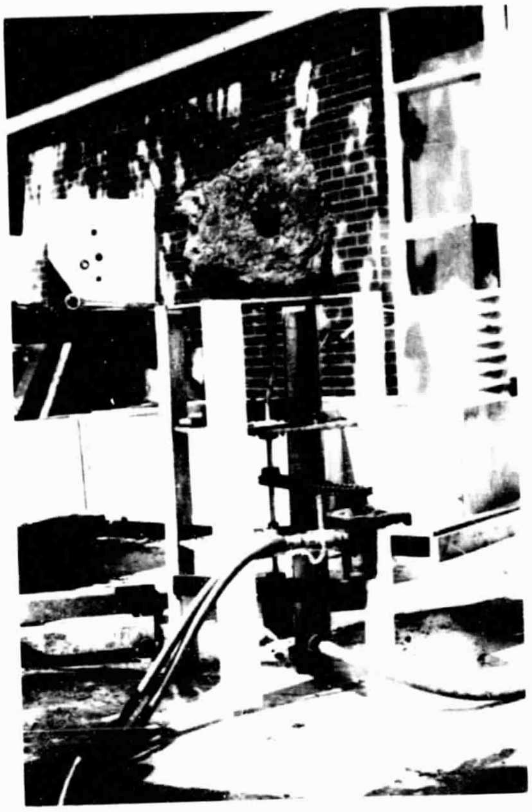

Fig. 3. The test equipment.

using pins to ensure exact location for contour matching and held in place by a retaining head which screwed over the nozzle onto the tubing.

Sample Preparation

Coal deteriorates rather rapidly upon exposure to air and moisture and for this reason it was considered important that only fresh coal samples be used in this experiment. Unfortunately this criterion meant that coal could not be obtained until the conclusion of the industrial dispute within the mining industry which lasted through the first three months of 1978 and therefore delayed the initiation of this program. Coal samples were ultimately obtained from a mine in north central Missouri where a stripping operation had uncovered a coal seam 5 feet thick at a depth of approximately 35 feet. The coal was bituminous from the Bevier seam. It contains sulphur, average 4.1% (Ref. 9) and the samples obtained were interlain in part with lenses of pyrite. Since this, however, is likely to be encountered within many coal seams, this did not, it was considered, detract from the samples which could be used, but instead provided an additional parameter in the tests.

The samples were hand-collected at the mine and ranged in thickness from four inches to ten inches. These samples were transported back to Rolla together with samples of the overlying sandstone and the shale which predominated at the mine. Upon arrival at Rolla, the samples were cleaned to remove loose material and were made up into specimen blocks 28 inches in dimension.

The blocks were prepared with the sandstone or shale placed, first, in the bottom of a preformed wooden box. The particular coal block was placed on the rock to give as large contact area as possible and a concrete: Hydite mixture was then poured into the box to just cover the

upper coal surface. The blocks were left to set in the forms for three days and were then removed and air dried for two more weeks prior to the test. The coal had been coated by the concrete in order to protect it from further weathering and this protective cover was chiseled from the coal surface to leave a relatively smooth face just prior to the testing of each rock sample.

Apart from the samples prepared using mine rock, twelve samples were also prepared using Berea sandstone as the underlying rock material. This rock was chosen since it is relatively common, is relatively homogeneous and is a rock commonly used in jet cutting research. The exact composition of the blocks prepared for this test program are as shown in Table 1.

Initial Testing

The basic premise on which this contract was undertaken is the fact that where a water jet cuts into a coal sample, that the jet will infuse along weakness planes in the coal so that, if a cylinder is cut vertically upwards within the coal that the central core of that cylinder will be sufficiently weakened that it will be removed by the force of gravity. Conversely, where the water jet cuts into a rock such as sandstone, the very localized cutting action of the water jets is such that where a cylinder is described by the water jet path, only a thin slot will be cut into the rock. It was important initially to verify that this differentiation between coal and other rock occurs and to determine under what parameters it could, consistently, be anticipated.

In previous testing using Berea sandstone, it has been found that the jet will cut this rock much more favorably than many other rocks. This rock was therefore chosen as the test material to parameterize the

Table 1. Sample Composition

Date of Manufacture	Sample Number	Depth of Coal (inches)	Thickness and Type of Roof Material (inches)
June 2, 1978	1	6-1/4	2-1/2 mine shale
	used (2)	6-3/4	3-1/4 mine shale
	3	7-3/4	2-3/4 mine shale
	4	5-1/2	2-3/4 mine shale
	5	9-3/4	2-3/4 mine shale
	6	7	1 mine shale
	7	4-1/2	1-3/4 mine shale
June 5, 1978	8	6	~4 mine sandstone
	9	7	~4 mine sandstone
June 6, 1978	10	6-1/2	~4 mine sandstone
	11	6-1/2	~4 mine sandstone
	12	6-1/2	~4 mine sandstone
	13	5-1/2	3-1/2 - 4 mine shale
	used (14)	6-1/2	3-1/2 - 4 mine shale
	15 (15)	7-1/2	3-1/2 - 4 mine shale
	16	5-1/2	3-1/2 - 4 mine shale
June 9, 1978	used (17)	6-1/2	2-3/4 Berea sandstone
	used (18)	6-1/2	2-3/4 Berea sandstone
	19	9-3/4	2-3/4 Berea sandstone
	20	6-3/4	2-3/4 Berea sandstone
	21	7-1/4	2-3/4 Berea sandstone
	22	6-1/2	4 mine shale
	23	4	4 mine shale
June 11, 1978	24	6	3 Berea sandstone
	25	7	2-3/4 Berea sandstone
	26	8	2-3/4 Berea sandstone
	used (27)	4-1/4	3-1/4 Berea sandstone
	used (28)	6	3 Berea sandstone
	used (29)	4	3 Berea sandstone
	30	3-1/2	2-1/4 Berea sandstone

jet configuration required for the jet to cut a slot in the rock, rather than a hole. In the first series of tests, three offset radii were tested and four nozzle diameters. These are shown in Table 2 together with the results. The tests were carried out over a 5 second time frame in order to give the maximum time for damage to the rock and were carried out, with the exception of the tests with the .064 diameter nozzle, at a jet pressure at 10,000 psi. This pressure could not be achieved with the largest nozzle diameter because of the capabilities of the pump and with a 0.064" diameter nozzle, the tests were carried out at 8,800 psi.

The results of the tests showed that it was only at the largest radius that the jet would consistently cut an annulus in the rock rather than removing some of the central core, although the smaller diameter jet cut an annulus even at the smallest offset radius of the cutting arm. The first phase of the program could therefore be described as successful insofar as the water jets would cut a circle in the rock while leaving the central core intact (Fig. 4).

Consequent to the tests, a single test was carried out on an unconfined sample of coal and it was shown that under equivalent conditions, where the water jet was cutting an eccentric radius of 1 inch using a .04 inch diameter nozzle at 10,000 psi with a cutting time of 5 seconds that the central core of the cylinder was removed by jet action (Fig. 5). Unfortunately since the coal was unconfined the sample split apart approximately half way through the test and a complete definition of the depth of the hole could not be made. The basic result however was confirmed. It was therefore decided that further testing would be carried out using the multi-material target samples which have been described as above.

Table 2. Influence of Jet Parameters on the Cavity Configuration in Berea Sandstone

a) Shape of Cavity

Nozzle Diameter (in.)[1]	Offset Radius[2] (Nominal in.)			
	.5	.75	1.0	1.0
.02	.56[3]	1.13	1.38	
.03	.69*	.88	1.63	
.04	.50	1.38*	1.50	1.88*[4]
.064	1.00*	1.00	1.25	

(1)The jet pressure was 10,000 psi except for the .064" nozzle when it was 8,000 psi.

(2)The rotation speed was held constant at approximately 750 rpm.

(3)The internal diameter of the annulus or the external diameter of the hole is given, an asterisk marks such a sample where no central core remained.

(4)Coal sample.

b) Depth of Cavity

Nozzle Diameter (in.)	Offset Radius (Nominal in.)			
	.5	.75	1.0	1.0
.02	2.5	2.5	1.75	
.03	3.31	3.38	2.00	
.04	3.13	4.00	2.63	4.0[4]
.064	7.50	5.81	5.63	

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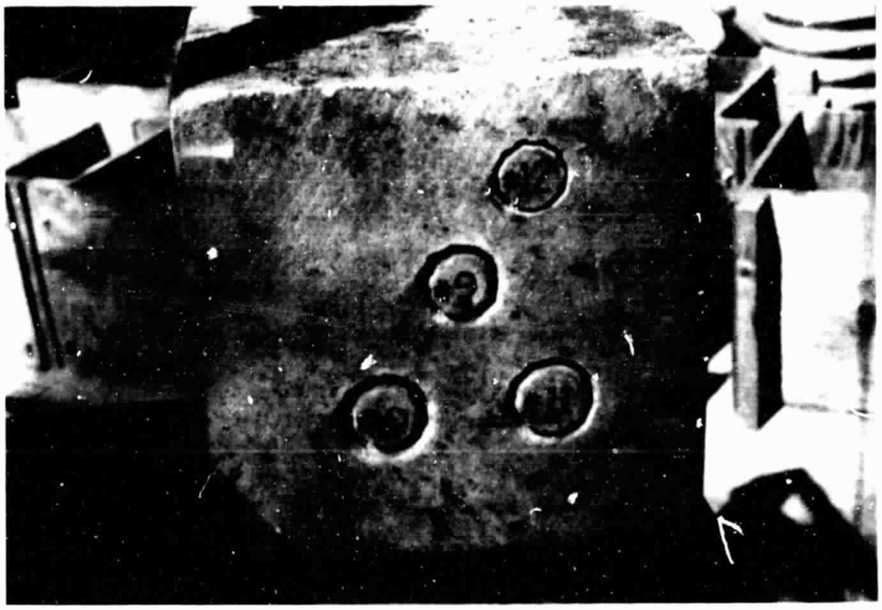

Fig. 4. Slots cut into sandstone showing the residual central core.

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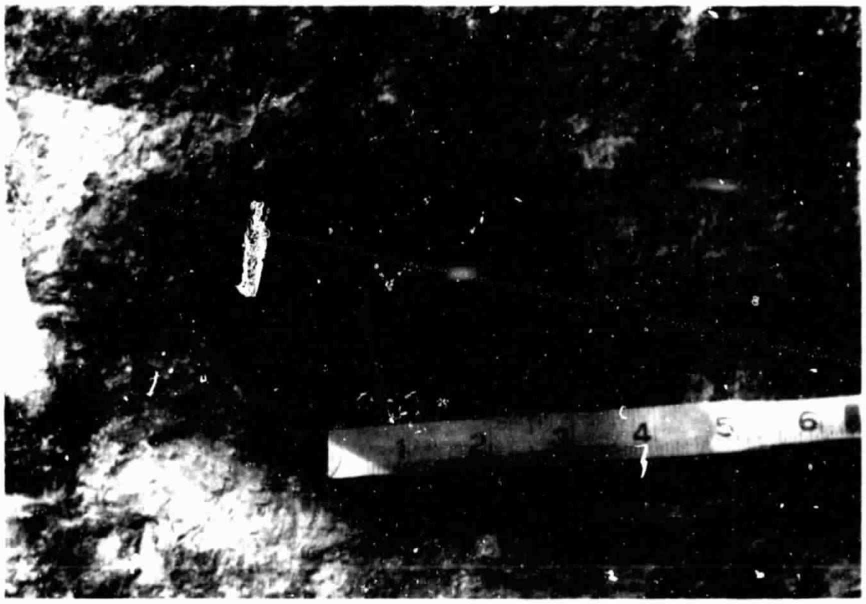

Fig. 5. Slot cut in coal showing removal of the central core.

Concept Verification

In order to conserve the samples prepared using mine material, preliminary targets were selected in which the coal was backed up by the Berea sandstone. This would also serve to confirm the findings of the first set of results. The nozzles were rotated at a relatively high rpm (approximately 750) during these tests which were carried out with the jet set at a 1 inch offset radius. The jet was exposed for 5 seconds and the nominal stand-off distance was approximately 1.8 inches. Three repetitions were made of the tests as shown in Table 3 to determine under what conditions the water jet would adequately penetrate through the coal to the target material and slot it while removing all the coal.

The results of these tests showed that the smaller nozzles were not adequate to the task required. Although the .04 inch nozzle, for example, was capable of penetrating up to 6¼ inches into the coal within the 5 second period of the test, the specifications of the contract required that the system be able to discriminate at up to 8 inches of coal thickness. It was therefore concluded from these tests that it would be necessary to use the .064 inch nozzle in order to cut through the required thickness of coal within the time frame required. It was also noticed that where the smaller nozzle diameters were used the jet would not cut a straight walled cylinder through the coal but rather the hole would cone towards the rear so that the 1-5/8 in.diameter hole at the surface was reduced to 1 inch at the bottom and this was not always a sufficient diameter to cut a slot in the rock rather than a cylinder (Fig. 6).

A test was carried out with the largest of the nozzles capable of operating at 10,000 psi (.040 inch nozzle) to determine the effects of rpm on cutting depth and to determine if the jet could cut completely through the coal within an adequate time frame. These three tests

Table 3. Jet Penetration through Coal: Rock Samples to Detect the Interface

Test Number	Nozzle Diameter (in.)[1]	Hole in Coal	Hole in Rock
17	.02	3" deep - did not remove all the core	did not reach the rock
18		3.25" deep - removed all core	did not reach the rock
25		5.0" deep	did not reach the rock
16	.03	4" deep - tapered from 1.5" to 1"	no significant damage
19		2.25" deep - tapered from 1.63" to 1"	did not reach the rock
24		4.75" deep	did not reach the rock
15	.04	4" deep - removed all coal	no significant damage
20		6.5" deep - tapered from 1.5" to 1"	no significant damage
23		2.38" deep	did not reach the rock
14	.064	4" deep - removed all coal	cored from 1.87" to 0.5"
22[2]		6.5" deep - removed	2.75" deep slot

The tests were carried out with a nominal 2.25" standoff and at approximately 750 rpm jet rotation speed on a nominal 1" eccentric radius with a 5 second jet exposure time.

(1) Tests at 10,000 psi, apart from the 0.064" diameter nozzle where the pressure was 8,800 psi.

(2) Sample 21 was not included for irrelevant reasons.

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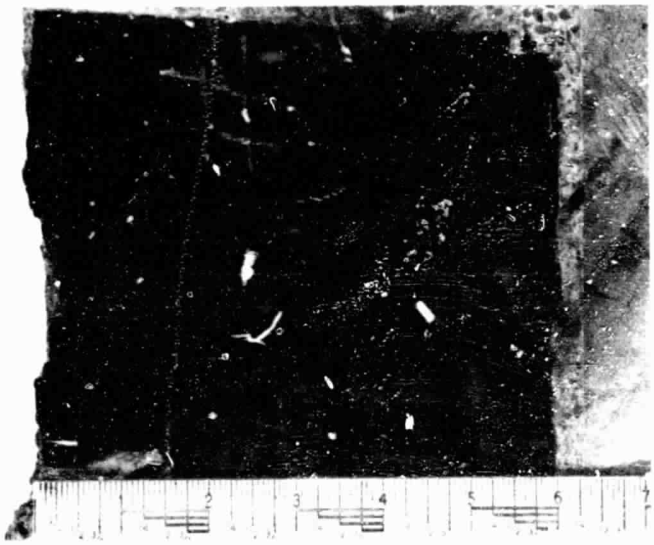

Fig. 6. A hole cut in coal showing passage through pyrite lenses, but coning of walls with a small diameter jet.

described (Table 4) indicated that while the jet was capable of cutting through a 6 inch sample of coal within 5 seconds and that the rpm was not a factor in the achievement of this penetration, that the jet was not capable of cutting to the satisfactory depth where the exposure time was reduced to 3 seconds. This confirmed the conclusion that the largest nozzle diameter would be required for such a test system particularly since it was noted that in all four of the tests the hole diameter was reduced considerably with depth into the coal.

As a result of these tests, it was determined to do a further test examining the potential benefit to be achieved by increasing the pressure of the .04 inch diameter jet to determine whether in fact the jet could be made to cut through the 8 inches of coal within a time frame of 3 seconds if the pressure could be increased. As a result three tests were carried out successively at 8, 10, and 12,000 psi (Table 5). It was determined from these tests that the jets were still incapable of cutting at a depth of greater than 5-3/4 inches even at 12,000 psi and it was therefore concluded that the only alternative was to go to the .064 inch nozzle diameter.

A series of tests were carried out at 4, 6, and 8,000 psi using this nozzle and it was found that for the 3 second exposure at 4,000 psi (Table 5) the sample was not completely penetrated, however at 6 and 8,000 psi the jet cut completely through the coal into the sandstone in 3 seconds. Where the pressure was at 8,000, the jet not only went through the coal but also completely through the sandstone (Fig. 7). In consequence it was determined to carry out a further test reducing the exposure time to 2 seconds. This was the shortest practical duration of the tests that could be carried out with the system as constructed and six tests were carried out with a 2 second exposure, .064 inch nozzle

Table 4. The Effect of Time and Rotational Speed on the Penetration of Coal

Run	Time (secs)	Rotational Speed (rpm)	Depth (in.)	Comments
26	5	835	6.25	hole tapered
27	5	200	6.50	hole tapered
28	3	835	5.13	hole tapered

The tests were carried out with a 0.04 in. diameter nozzle, at a nominal rotational eccentricity of 1 inch, 2.25 in. standoff, at 10,000 psi jet pressure.

Table 5. The Effect of Jet Pressure and Exposure Time on the Penetration into Coal and Rock

Run Number	Nozzle Diameter (in.)	Jet Pressure (psi)	Time (sec)	Cut in Coal	Cut in Rock
31	.04	8	3	5.06" deep hole	did not reach rock
29	.04	10	3	5" deep hole	did not reach rock
30	.04	12	3	5-3/4" deep hole	no significant change
34	.064	4	3	4.75" deep hole	did not reach rock
33	.064	6	3	6" deep hole	marked rock
32	.064	8	3	6" deep hole	3" deep cylinder left (to back of block)
38	.064	4	2	4.5" deep hole	did not reach rock
35	.064	6	2	6" deep hole	slotted rock
39	.064	6	2	8.38" deep hole	slotted rock
36	.064	8	2	6.75" deep hole	shale backing disintegrated
37	.064	8	2	6.75" deep hole	shale backing disintegrated
40	.064	8	2	8.5" deep hole	slotted sand-stone

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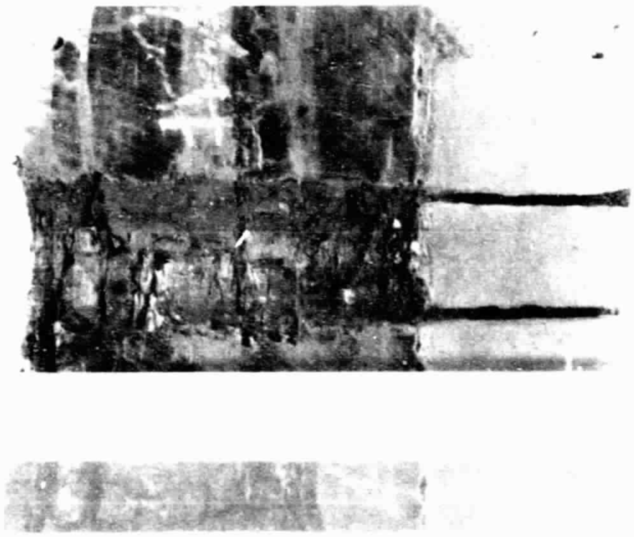

Fig. 7. The penetration of 6 inches of coal showing the contrast between cutting coal and rock.

diameter with varying jet pressures.

At 4,000 psi the jet only cut 4¼ inches into the coal but in the first test at 6,000 psi the cut went completely through the coal to the underlying sandstone, a distance of some 6 inches. Similarly where the tests were carried out with coal backing on shale, within the two second time and at 8,000 psi the water jet cut completely through the coal and into the shale. A further experiment was then carried out using samples of coal greater than 8 inches in size and it was again found that with 6,000 and 8,000 psi pressure that the water jet would completely penetrate through the coal into the sandstone within a 2 second time exposure. In both cases the water jets completely removed all the coal but left the sandstone in a slotted condition. This result, it is felt, was consistent enough to verify the concept originally proposed which was to use a water jet to discriminate between coal and shale and also to demonstrate that this could be done within a meaningful time frame for the operation to be carried out on a longwall face.

It has been shown possible to penetrate through more than 8 inches of coal within a time frame of less than 2 seconds removing all the coal from the cylinder drilled out but leaving the central core present where the jet penetrates into sandstone (Fig. 8). It can therefore be concluded that high pressure water jets can be used as a discriminating system between coal and the overlying roof rock in the manner proposed. Insofar as the pump at 8,800 psi put out 10 gallons/minute and at 8,000 and 6,000 put out correspondently less fluid and the holes were drilled in a time of less than 2 seconds,the amount of water that would be required to drill each hole would be of the order of 1.3 quarts. This is a relatively small volume of water and would not interfere in any way with the operation of the face and is of sufficiently small volume that a

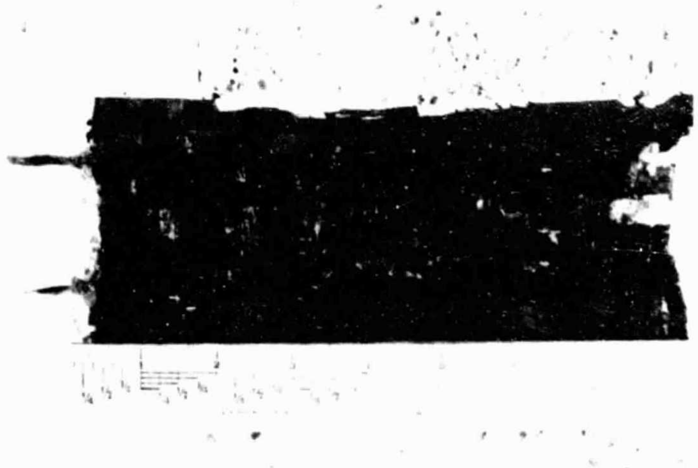

Fig. 8. Successful cut through 8 inches of coal to sandstone showing the differentiation in cutting.

system could very easily be designed to provide this flow on a single stroke intensifier basis. This point will be further discussed in Chapter 4 of this report.

Conclusion

The conclusion, therefore, of the physical testing was that the water jets could be used to adequately discriminate between coal and any other overlying rock in the manner initially proposed, i.e. that where a jet is used to describe a cylindrical cut through the material, the central core of the cylinder will be removed where such a core is made of coal but will not be removed when the core is in rock. The parameters required for this appear to be that the jet is operated at a pressure of at least 6,000 psi for a time duration of 2 seconds at a rotational speed of the order of 200 rpm through a nozzle of .064 inch diameter. Such a system would require approximately 1.1 to 1.3 quarts of water and is capable of cutting 8 inches of coal as called for in the initial contract specification.

CHAPTER THREE

INSTRUMENTATION TO MEASURE THE DEPTH OF THE HOLE IN COAL

Introduction

The program being carried out at the University to detect the interface between coal and shale is in two parts. The first part has previously been described in Chapter Two and consists of establishing a hole through the overlying coal left after the passage of a shearer to the interface between the coal and the superincumbent roof rock. Having established this hole it is necessary to measure its depth as the unit advances.

While it would be relatively simple to have some form of extendable measuring system which could be inserted into the hole, calibrated to establish the hole depth; such a system, it was felt would be too susceptible to damage for it to be viable in the hostile environment of a longwall coal mine face. For this reason, a noncontact method of depth measurement was sought.

Commercial System Availability

Many different systems were reviewed during the course of the program. However, almost at the end of the contract period two new developments in the field of photography were announced which seemed to very readily solve the problems herein being evaluated. Since the equipment had been intensively developed at a relatively high cost it would seem wise that advantage be taken of these developments. The two systems developed are for the automatic focusing of a photographic camera.

One system, commercially available, has been developed by Honeywell

and known as the Visitronic Autofocus System. This has been licensed by Konica and forms an integral part of the Konica Model C35AF 35 mm Camera. The system has also been developed and is commercially available as the focusing device for a Sankyo Super 8 Movie Camera, Model ES44 XLVAF (Ref. 10). A second system has been developed by Polaroid and will become commercially available in the fall of 1978. This latter system uses an ultrasonic chirp and is capable of focusing from 10 inches to infinity and may have application in mining; however, the chirp consists of four frequencies, 60 kilohertz, 57 kilohertz, 53 kilohertz, and 50 kilohertz (Ref. 11). Due to the extreme noise environment within the vicinity of operation of a shearer, this equipment may have some trouble operating.

Because of the availability of the system and its relatively low cost, an investigation was made of the Honeywell method of autofocus. The Honeywell Corporation was contacted but unfortunately due to the agreements which they had made with their clients in regard to the licensing of the system, it was not possible for them to provide the University with any information about the autofocusing system they had developed unless the University licensed the development, an impractical course of action.

A camera was therefore obtained from a local supplier to evaluate the practicality of using this system as a distance measuring device to be located on the shearer. The model investigated used the 35 mm camera and the automatic focusing system developed for it. However, in the development of equipment for the installation on a shearer, it is recommended that the system developed for the Super 8 Movie Camera be utilized since this gives a continuous monitoring of position, which would be required during the operation of the machine. However, the

basic potential of this system could be evaluated using the 35 mm camera system, and since this was readily available this was the system that was examined.

Test Evaluation of the Autofocusing System

A Konica 35 mm VAF Camera was purchased and partially disassembled in order to observe the size of the components and the operation of the components involved in the autofocusing function of this camera. The module occupies a space of approximately 2" x 1" x 5/8" on the top of the camera (Fig. 9). It consists of a dual mirror pair, one mirror of which is fixed and the other of which can oscillate, both of which direct light from the front of the camera into a Parallex image converter.

The autofocus feature of the Konica C35 AF Camera begins operation as the film is advanced. Concurrent with the film advance mechanical energy that will be used to focus the lens system is stored in a spring. When the shutter release is pressed, electrical power is applied to the control electronics, activating the Visitronic module prior to the release of the lens mechanism.

The first event to occur is that the rotating mirror begins its scan from the far position, rotates to the near position, reverses direction and returns to the far position. While the mirror is rotating from the far position to the near position the Visitronic module compares the scenes viewed by the rotating mirror and the fixed mirror. Each mirror produces an image that impinges on two image detector areas within the module. The module notes the position of the rotating mirror that gives the maximum correlation between the two images (Fig. 10).

As the rotating mirror reverses direction, a time interval clock within the control electronics is started. When the rotating mirror

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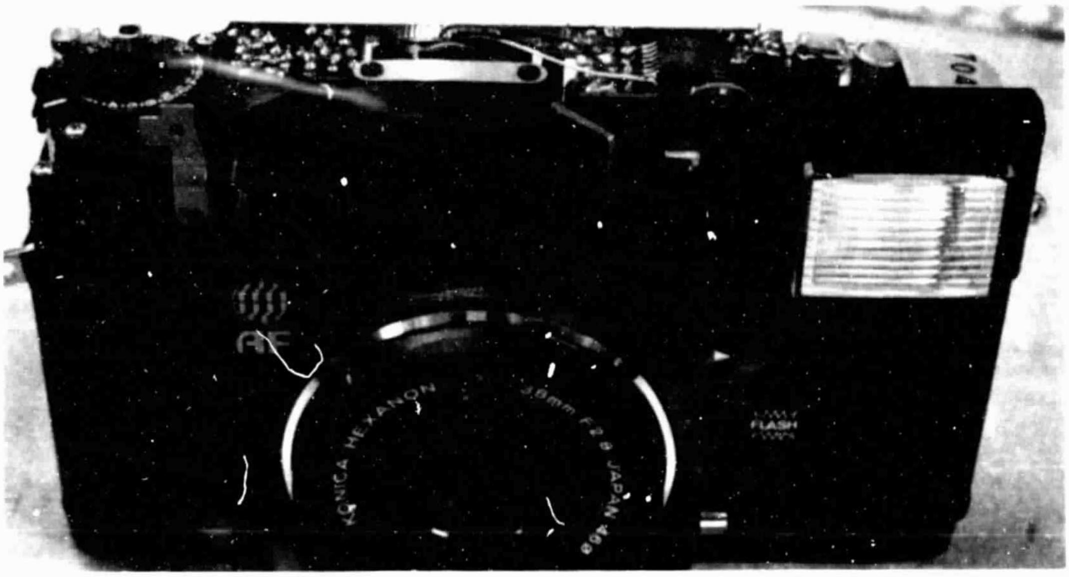

Fig. 9. Konica camera showing the
size of the autofocus module.

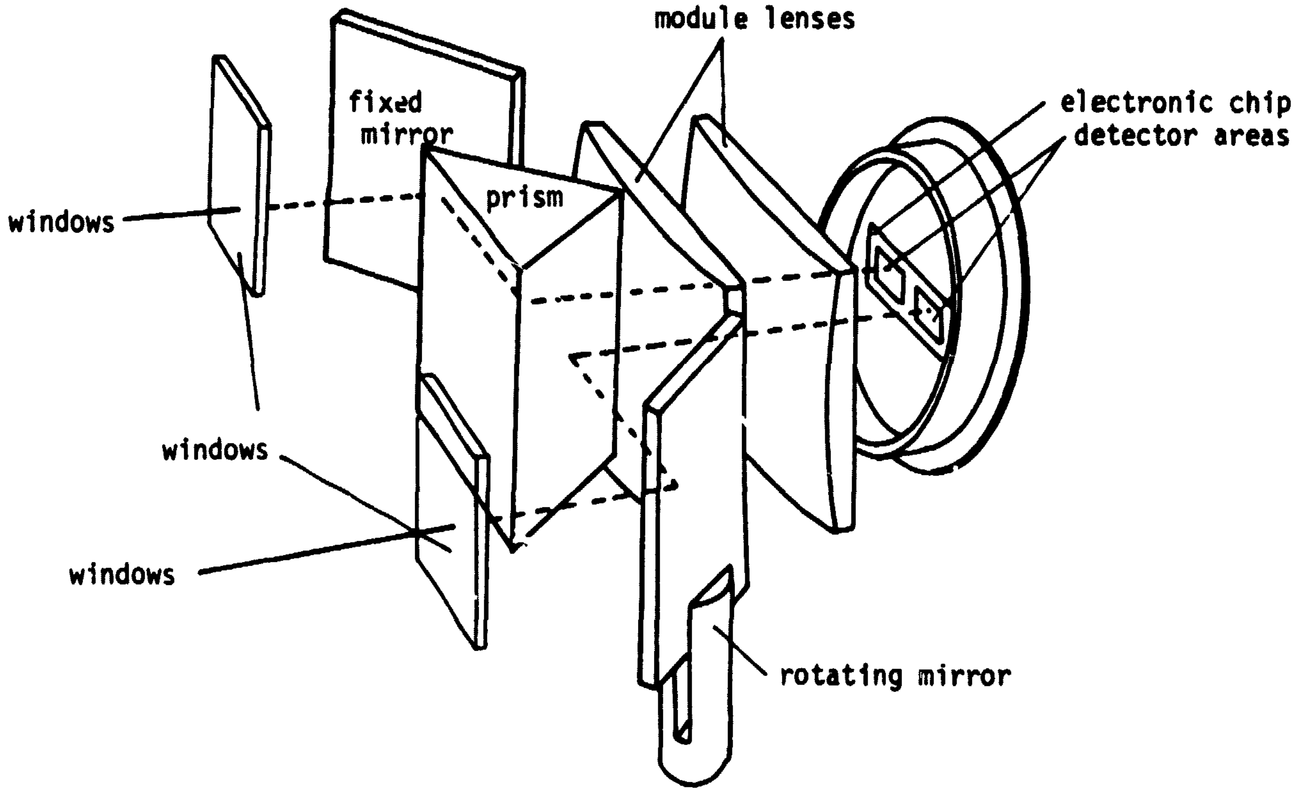

Fig. 10. Major Components of the Automatic Focusing System of the Honeywell Automatic Focusing Device showing the light path.

reaches the position of the maximum correlation, the Visitronic module transmits a pulse to the lens control electronics that stops the time interval clock. The control electronics then determine when to release a solenoid within the lens assembly which will engage a ratchet, stopping the lens movement (Fig. 11). The lens then moves. It starts at an extended forward position, and can travel through a middle position to a rest position. The latter two positions correspond to the near focal point and the infinite focal point, respectively, for the camer lens. The position of the camera lens determines the relative angle of the rotating mirror with respect to the Visitronic module by a mechanical linkage. After the proper time interval has elaspsed the solenoid is released allowing the ratchet to engage, thereby halting the lens movement. The lens is now in the proper focusing point and the shutter then opens.

The particular controls of the camera had to be determined experimentally due to the nature of the arrangement with Honeywell descrived above. It was necessary to go into this detail in order to determine the specific output from the control device which could be utilized as an input signal to any steering system on the shearer. The module was partially disassembled and the controls traced and analyzed through the use of an oscilloscope to determine the signals transmitted as the autofocusing mechanism operated. The signal required was the controlling signal to the solenoid, which adjusted the focal length of the camera lens. This signal could, if directly correlated with a distance to the target, be measured and would therefore equally well serve as a distance measurement to the target for the control of the shearer. Analysis of the signals was undertaken, using a pair of oscilloscopes. Photographs taken from the screen of a Tektronix 545 storage oscilloscope represent signals emanating from test points on the Visitronic

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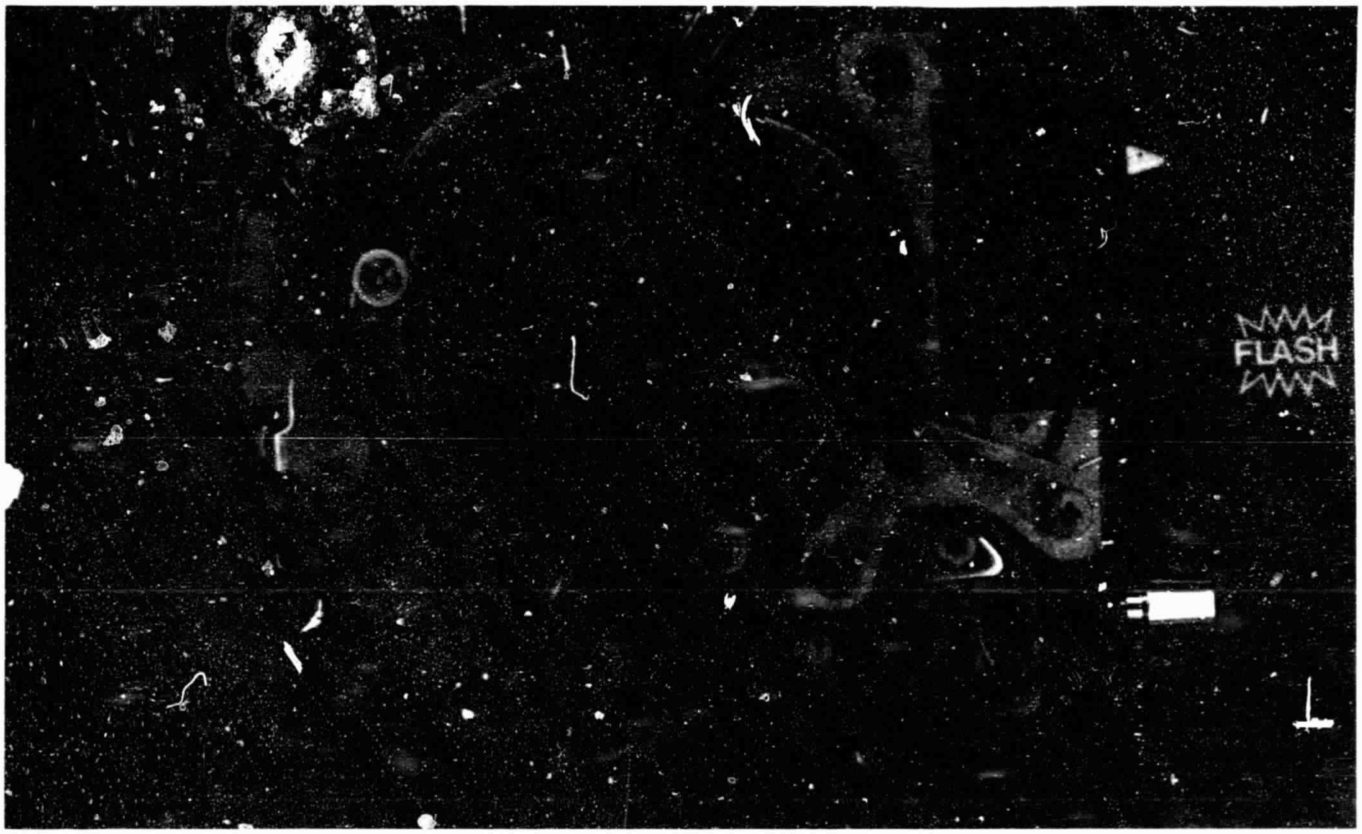

Fig. 11. Detail of camera construction showing the solenoid mechanism for stopping the lens.

module, the lens synchronization switch and the lens solenoid. The signal coming from the lens synchronization was a series of pulses which generated from the module. The signals varied randomly in time and amplitude as the rotating mirror was rotated. However, the last pulse in this series of pulses occurred just prior to the release of the solenoid, generally in the time interval of 12 to 21 milliseconds when the range of the target was 45 inches to 50 inches, respectively.

It was noted that the equipment is, in this particular instance, accurate down to a focal distance of approximately 41 inches only. This was verified in a series of experiments carried out with the unit operated in a photographic mode and it was found that the unit would not focus where the subject distance was less than a meter.

While this is a particular characteristic of the system set up for this particular camera, it is not a characteristic of the system as a whole. The characteristics obtained from the evaluation have shown that the camera is able to discriminate in less than one inch increments, as shown in the table, and because of the step function it can actually discriminate to a much finer degree of accuracy. The equipment which was available for analysis within the time frame available at the University was not such that a much higher degree of accuracy of measurement could be achieved than that obtained and represented in this table. However, the accuracy can be made much greater if so desired since the distance measurement is represented as a signal time, and this can be measured to whatever degree of accuracy is required for the system involved.

The potential accuracy is a function of the electronics used in the analysis of the time signal. While this can be brought well within a measuring accuracy of 0.01 inches the time necessary to build such a

unit was not justifiable at this stage.

A calibration made using visual analysis of data obtained from oscilloscope read-out (Fig. 12) showed an accuracy of 0.1 inches with a relatively unsophisticated arrangement and this was considered adequate to justify the conclusion that the autofocus system is a viable one.

In the program as designated, the system is compared with a nucleonic sensor which has been demonstrated as having a measuring accuracy of one inch, and this system has been shown to be accurate to within the level in this preliminary evaluation. It was noted in the evaluation of this system that the accuracy of readout was less than 1 millisecond of variation over a distance of 45 inches. These variations were due in part to triggering level shifts in the oscilloscope. This problem could readily be eliminated if a digital timing signal had been used as opposed to reading these time intervals on an oscilloscope trace.

The conclusions from the evaluation of this system are that the system can be readily modified to read the location of the back of the hole cut by the water jet.

It is recommended that the way the system be developed is based on the Sankyo modification of the Honeywell system wherein a continuous monitoring device has been developed rather than the single shot option of the 35 mm camera as used by Konica. In this manner two sets of signals will be developed. There will be the general signal which is a monitoring of the position of the coal roof in relation to the instrument as the shearer moves down the face and then at the designated interval the instrument will measure the depth to the bottom of the hole drilled in the coal, thus giving the depth of the coal shale interface. Therefore one obtains two measures of the coal location in this instance,

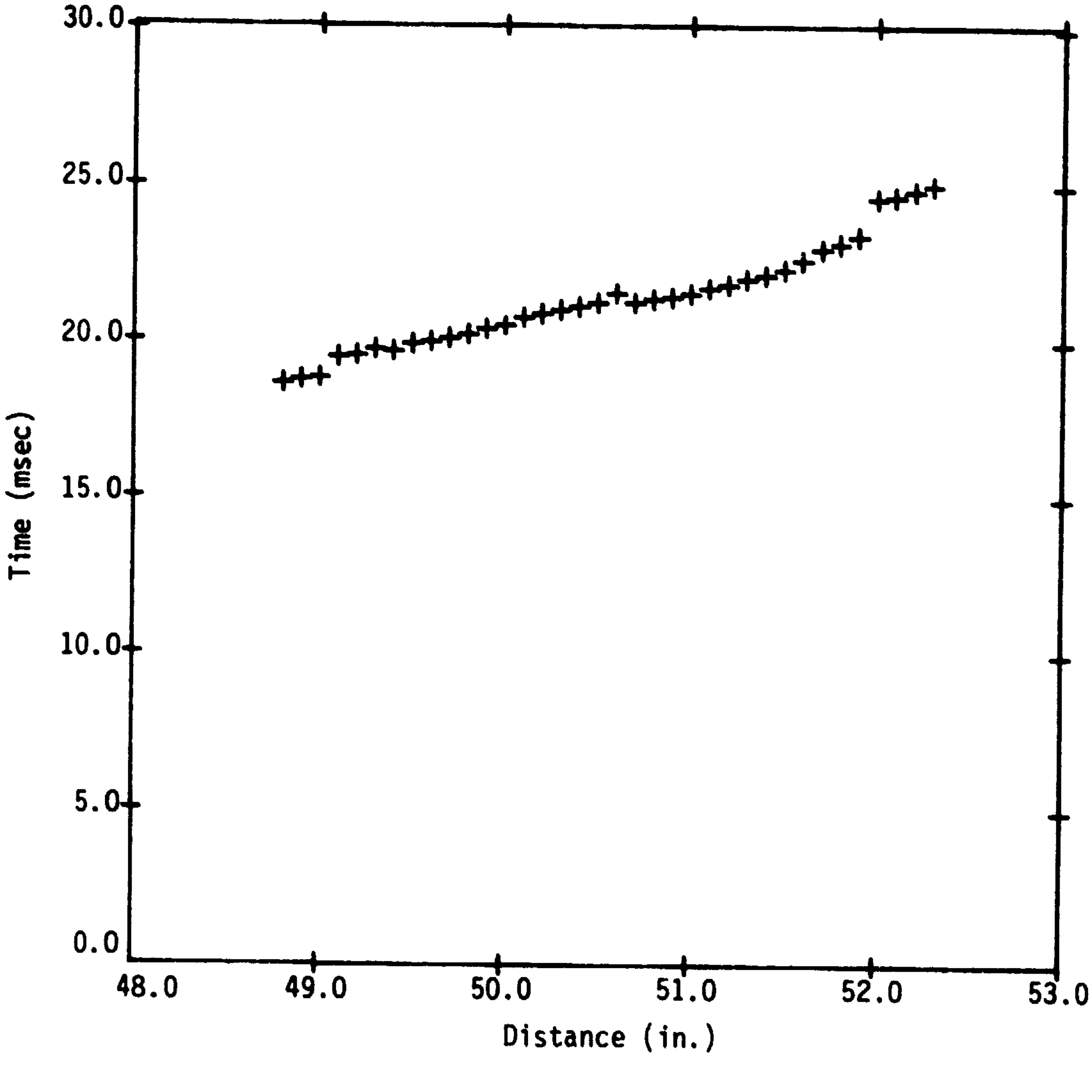

Fig. 12. Correlation Between Time and Signal and Distance

rather than the single readout which is generally given with a nucleonic sensor.

The package is a relatively small one and can therefore be easily mounted on the shearer. It is relatively inexpensive, the autofocus feature of the Sankyo system is priced retail at $200 additional to the price of the basic camera, and the dimension of that is approximately 3" x 2" x 1". Experiments were carried out at the laboratory which show that the system is capable of focusing on a black target so that a minimum amount of light will be required for the system to work, and the system has been established to give the necessary accuracy required for the steering of the longwall system. It is therefore recommended that such a system be incorporated in the second generation of this program.

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

Introduction

The purpose of this research grant was to demonstrate that a water jet driven device could discriminate between coal and overlying roof rock. Once this could be demonstrated, a second purpose was to identify a system which would provide the location of this interface, the final objective being to indicate how this might be attached to a conventional operating shearer.

In the second chapter of the report it has been shown that a high pressure water jet system can provide a method of identifying the coal roof interface. The method leaves a hole to the depth of the coal and approximately 1 in. in radius. In the third chapter it has been shown that the autofocusing feature developed by Honeywell for photographic equipment will allow a direct measure of the depth of the hole.

In this concluding chapter, the methods of attaching the device to an existing shearer and the benefits and problems likely to be encountered will be discussed.

Package Dimensions and Locations

There are three components which must be considered in the attachment of the water jet identification device (WAJID), the drilling component, the measuring component, and the supply pump.

It is proposed that the drilling unit be similar to a model developed for a coal drilling concept, as a first prototype (Fig. 13). This device incorporates a hydraulic drive motor and a rotary coupling into a package which is fed by three cables, a high pressure hose for the water and a

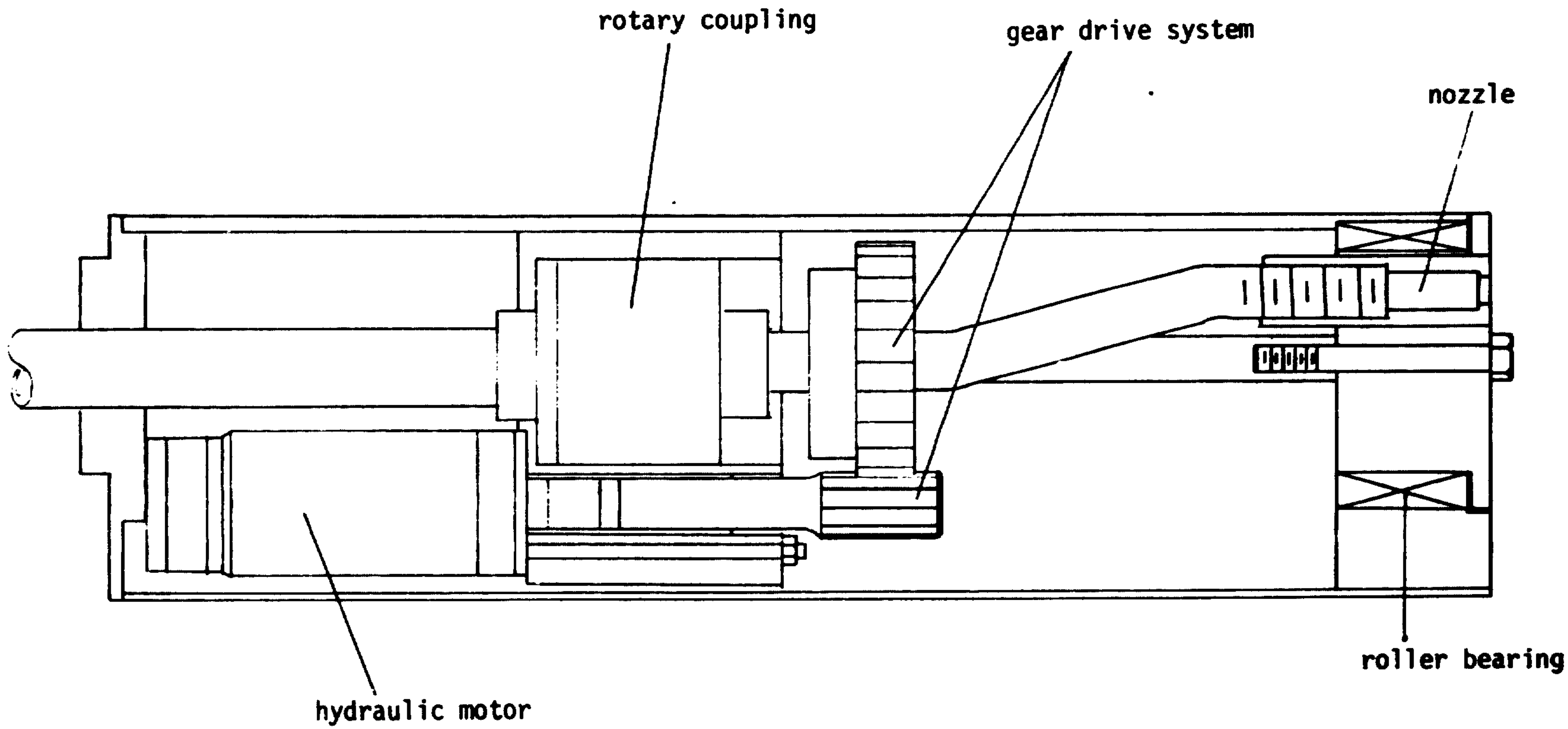

Fig. 13. Proposed Water Jet Slotting System

hydraulic hose intake and return line for the hydraulic motor. This resolves into a package less than 7 in. in diameter and 1 ft long. This can be readily located behind the leading cutter drum to give the required readings. It must, in contrast to the nucleonic sensor, be held in place for the two seconds while the hole is drilled. Unlike a conventional drill, however, the unit does not extend into the hole, require a high thrust, or need frequent bit replacement. The light weight of the unit means that it can be built relatively easily and a control mechanism can be simply developed to move the unit relative to the machine body. During a two second advance the motion of the machine may be compensated for by moving the drill itself.

One way in which this might be achieved is to put a dual connected cylinder pair on the shearer body. One cylinder would be located so that the piston would engage the haulage chain (which is rigidly fixed). As the piston is then compressed, as the shearer advances, the fluid is pushed from that cylinder to the cylinder attached to the drilling head. This will then push the drill back in a compensating motion during the time of drilling. (This will have the advantage of removing the problem of variation in machine speed).

The depth sensor, as discussed in Chapter 3, is one inch high, two inches wide and three inches long. This can be mounted in a recess on a steel plate directly behind the drill location and only control wires will be required to lead to the master control monitoring system on the machine.

The third component required is the high pressure pump required for the drilling, and the hydraulic power required for the rotation motor on the drill. Several options for this has been considered. One option was to integrate a single acting intensifier or plunger to the compensating

cylinder which holds the drill head steady during operation. This device (Fig. 14) would also incorporate a rachet and sprocket device on the drill steel so that as the piston was pushed into the cylinder, the drill steel was rotated over the ratchet and high pressure water was supplied to the nozzle. While this was considered to be a viable option, the high pressure system would need to be totally designed, based on a piston stroke of 8 inches to produce approximately 61 cu in. of fluid at 10,000 psi, requiring in turn a 3.9 in. diameter piston. Such a system is likely to become large and heavy and to require an expensive period for development.

An alternate system is therefore proposed. Small intensifier units are currently available from commercial companies, such as Flow Industries or McCartney Manufacturing Company. These units can be started under load and are, for the horsepower levels here required (approximately 30-50 hp) relatively compact units. The Flow unit, for example, weighs only 100 lb (Fig. 15). These intensifiers can be fed from a tap on the hydraulic drive line for the main haulage motor on the shearer. This can be done either at a manifold location or in a joint on the flow path, or from the accumulator in the chain tension release system. In the case of the Joy machine the power takeoff can also come from the ram actuators for the booms of the ranging drums, since this supply also is at 2000 psi.

Conventional pressure on this hydraulic line (Refs. 12, 13) is of the order of 2000 psi at 75 gpm flow. This is to provide the potential for the shearer to pull against up to 70,000 lb force at an advance rate of 30 ft/min. Since the conveyor cannot handle the quantities of coal this would generate (Ref. 12) there is considerable power reserve in the haulage system and this would be tapped for the system power. The advantage of using automatic steering is that it has been shown to reduce the

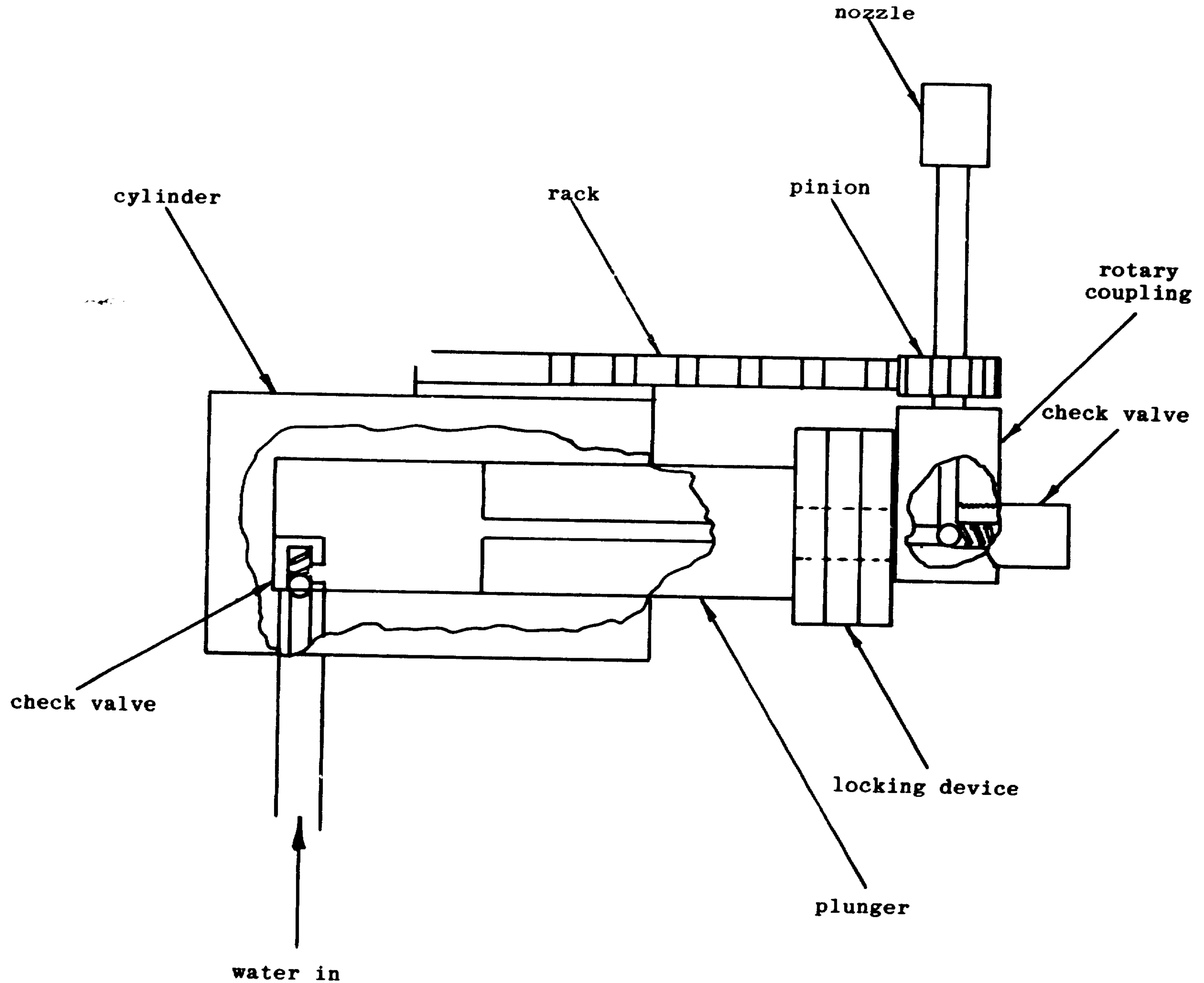

Fig. 14. Single Acting Intensifier.

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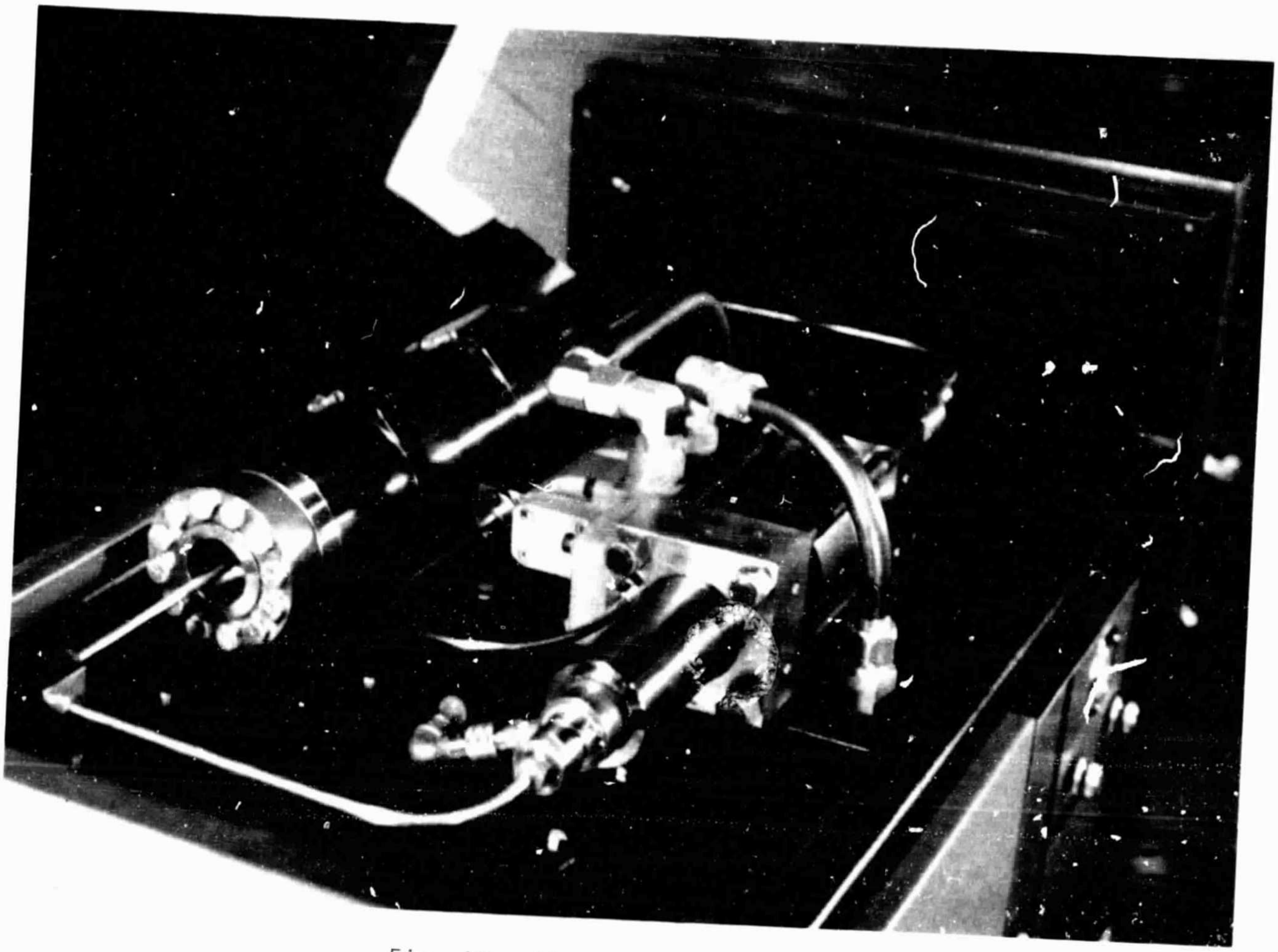

Fig. 15. Flow Intensifier.

haulage force required to move the unit along the face (Ref. 3) and thus this "released" power can be used to power the WAJID device.

Because of the relatively small size of this pump and because it is supplied by flexible hoses as well as delivering the high pressure fluid to a flexible hose, this means that the location can be chosen for convenience. It is suggested that the most appropriate place would be in a steel box (to protect from any falling debris) on the face side of the machine. This would have the advantage of keeping the high pressure fluid on the face and thus with the body of the machine between it and the operator of either the shearer or the support system.

Conclusions

This contract has served to demonstrate the capability which a water jet system has in delineating the interface between a coal seam and the overlying rock. A system can be developed which can be retrofitted to an existing machine, using in large measure commercially available components, joined together by flexible hoses, to drill holes in the coal roof to the interface, the depth to which can be then measured by a commercially available device which costs approximately $15. Power to the system would be drawn from the hydraulic haulage of the shearer, made available because of the lower forces required when the shearer is automatically steered.

Input to the steering device (itself not a part of this contract) would be in the form of a continuous signal indicating the position of the immediate coal roof over the shearer, with a regular interruption of this signal to give the depth to the overlying coal:rock interface.

The system relies on proven technology and the apparent following advantages over currently used systems would appear to be:

...the frequency of reading can be widely controlled, with reading frequencies from every foot at the closest increment;

...no positive contact with the roof is required;

...no calibration will be required;

...depending on the final sensitivity of the measuring system potential accuracies up to 1/100ths of an inch are possible;

...the system can be mounted in a small space to allow bi-directional shearing;

...the system can be made sufficiently simple and compact as to require infrequent maintenance by regular face operatives;

...the range is limited to 6 ft at present;

...the system is relatively insensitive to changes in rock and coal properties or the presence of thin dirt layers in the coal;

...the unit can be used in any seams a shearer can be used;

...the reading is taken in less than two seconds;

...once the unit has passed a skeptical face work can visually verify the accuracy of the unit and also observe the overlying strata.

Reccmmendations

Two further courses of action are proposed. Firstly, it is recommended that a detailed installation design be made to adapt the system herein described to an existing shearer body. The plan should include an estimate of cost of the equipment and the modification itself.

Secondly, it is recommended that concurrently a method be developed to monitor the relative position of the shearer relative to the floor coal:rock interface and the thickness of the coal left.

Such a program should take a year, at the end of which time a system will have been designed, built around existing hardware, which can, with minimum effort be fitted to an existing longwall machine in the field on an experimental basis.

It is recommended that such a program be funded in a subsequent year at the end of which time the concept will have been demonstrated and will be ready for commercial development.

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